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R-MATRIX ANALYSIS OF THE ^{239}Pu NEUTRON CROSS SECTIONS*

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Abstract ^{239}Pu neutron cross-section data in the resolved resonance region were analyzed with the R-Matrix Bayesian Program SAMMY. Below 30 eV the cross sections computed with the multilevel parameters are consistent with recent fission and transmission measurements as well as with older capture and alpha measurements. Above 30 eV no suitable transmission data were available and only fission cross-section measurements were analyzed. However, since the analysis conserves the complete covariance matrix, the analysis can be updated by the Bayes method as transmission measurements become available. To date, the analysis of the fission measurements has been completed up to 300 eV.

INTRODUCTION

The resonance-parameter description of neutron cross sections makes possible the simultaneous evaluation of different partial and total cross-section measurements and the assessment of uncertainties in reactor parameters.[1] The resonance parameter representation of neutron cross sections should be based on a physically sound nuclear reaction formalism, it should avoid the introduction of "smooth backgrounds" and it should be founded on a consistent analysis of fission, capture, and transmission measurements.[2]

Most of the early R-matrix multilevel analyses of the ^{239}Pu neutron cross sections extend over very small energy ranges, except for the analyses by Farrell[3] and by Derrien.[4] Farrell's analysis extends from 14 to 90 eV, but it is based only on the fission measurement of Shunk *et al.*[5] The analysis of Derrien extends from 4 to 205 eV. This analysis is of high quality above 40 eV but below that energy the parameters do not describe correctly the fission cross section.

This paper presents the results of a multilevel R-matrix analysis of the ^{239}Pu neutron cross sections up to 30 eV, and an analysis of the fission cross section up to 300 eV. Since only fission cross-section measurements were analyzed above 30 eV, the resonance parameters resulting from the analysis cannot be expected to reproduce correctly other partial cross sections or the total cross section. However, the analysis program SAMMY[7] utilizes the Bayes equations and keeps the covariance matrix of the resonance parameters so that new data can be successively incorporated into the analysis.

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THE ANALYSIS BELOW 30 eV

The measurements analyzed below 30 eV include recent fission measurements by Wagemans *et al.*,[8] Weston and Todd,[9] and Gwin *et al.*;[10] transmission measurements by Spencer *et al.*;[11] a simultaneous measurement of capture and fission by Gwin *et al.*; and below 1.0 eV some early measurements of fission, absorption, and alpha.[13]

The resonance parameters resulting from the analysis are listed in Table 1. The covariance matrix is available from the authors. The spin assignment of the resonances is that of Derrien. Two fission channels were assumed to contribute to the $J = 0^+$ states and one fission channel to the $J = 1^+$ states. Four bound levels and five levels above 30 eV were also introduced to "mock up" the contribution of the truncated levels.

A comparison between the fission data of Gwin *et al.*,[10] our evaluation and ENDF/B-V[14] in the energy range 10 to 30 eV is shown in Fig. 1. The figure illustrates that in the "valleys" between resonances our evaluation is more consistent with the measurements than is ENDF/B-V. Near the "peak" of the resonances the relative statistical accuracy of the data and the signal to background ratio are favorable because of the high reaction rate; hence the resonance parameters are constrained by the measurements. In the "valleys," however, low count rates and relatively high backgrounds result in large experimental uncertainties, and the value of the evaluated cross sections is largely determined by the model (by interpolation). Table 2 shows a comparison of fission cross sections integrated over intervals. The evaluations and measurements are consistent to better than 0.5% below 0.1 eV, but above that energy the 1980 data of Wagemans[8] and the ORNL-RPI measurement[12] are a few percent higher than the more recent data of Gwin *et al.*[10] and higher than our evaluation.

THE FISSION CROSS SECTION FROM 30 TO 300 eV

The present resonance analysis above 30 eV was based on the recent fission cross-section measurement of Weston and Todd[9] and on the high-resolution low-temperature measurement of Blons.[6] No properly documented transmission data were available when the analysis was started. In Table 2 the integrated value of the fission cross section from several measurements and evaluations are compared.

Although the average fission cross sections from the measurements of Blons and of Weston and Todd are consistent to within 5% (mostly a normalization difference), the shape of the resonances differ to an extent that could not be fully accounted for by the difference in temperature and resolution. Further work is needed to resolve this difference.

CONCLUSION

The present analysis yields a set of R-matrix resonance parameters which represent ^{239}Pu neutron cross sections below 30 eV consistent with most recent measurements.

As a first step toward extending the R-matrix analysis above 30 eV the fission cross-section measurements of Blons and of Weston and Todd were analyzed with SAMMY up to 300 eV. More detailed comparisons will be presented in a forthcomming publication.

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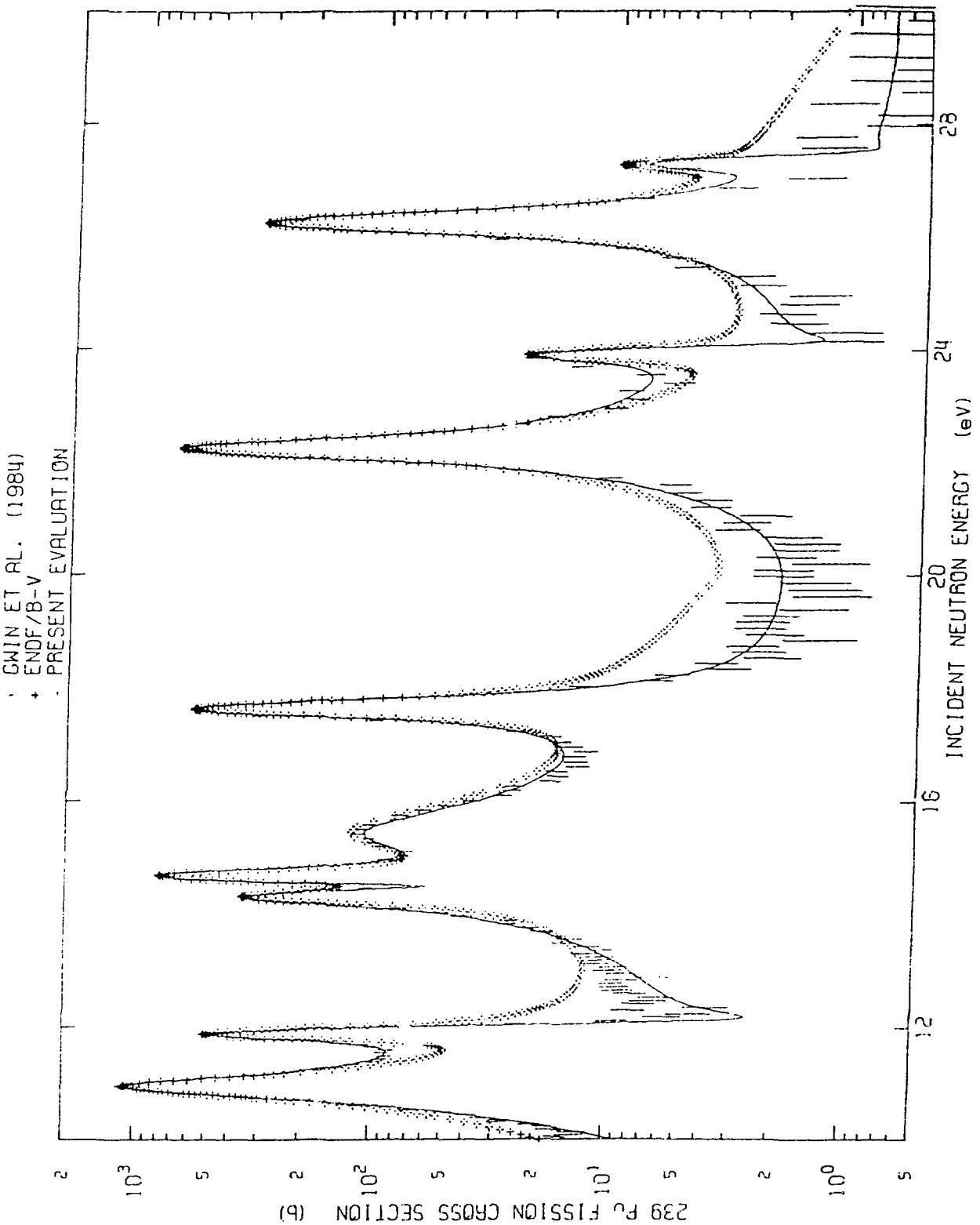
Table 1. ^{239}Pu resonance parameters

E_o (eV)	Γ_γ (meV)	Γ_n (meV)	Γ_{f1} (meV)	Γ_{f2} (meV)	J
−4.0613 ± 0.0010	37.3 ± 1.9	1.301 ± 0.018	−13945 ± 250	702 ± 34	0
0.29860 ± 0.00011	39.13 ± 0.12	0.25134 ± 0.00047	−2.11 ± 0.10	61.54 ± 0.27	0
15.45490 ± 0.00093	63.0 ± 2.6	1.746 ± 0.013	−0.759 ± 0.038	617.0 ± 6.3	0
32.32210 ± 0.00090	36.6 ± 1.7	0.8085 ± 0.012	−71.6 ± 3.0	−82.7 ± 3.2	0
41.6770 ± 0.0010	40.6 ± 2.0	12.38 ± 0.59	137.4 ± 6.5	−8.75 ± 0.44	0
−6.6600 ± 0.0010	22.8 ± 1.2	20.38 ± 0.70	291 ± 12		1
−2.0159 ± 0.0010	9.36 ± 0.47	2.189 ± 0.091	−1003 ± 41		1
−0.2701 ± 0.0010	7.41 ± 0.38	0.0524 ± 0.0012	1475 ± 45		1
7.82540 ± 0.00012	43.17 ± 0.4[illegible]	[illegible].78525 ± 0.00089	−45.76 ± 0.45		1
10.93920 ± 0.00026	38.66 ± 0.73	1.8235 ± 0.0020	−152.04 ± 0.78		1
11.89870 ± 0.00015	44.25 ± 0.45	1.0005 ± 0.0017	20.42 ± 0.35		1
14.32890 ± 0.00037	50.10 ± 0.81	0.7045 ± 0.0030	80.67 ± 0.83		1
14.67640 ± 0.00012	39.27 ± 0.32	1.9554 ± 0.0031	34.83 ± 0.30		1
17.64930 ± 0.00016	40.77 ± 0.37	1.8211 ± 0.0032	−35.06 ± 0.27		1
22.24930 ± 0.00028	48.73 ± 0.58	2.7532 ± 0.0066	−63.88 ± 0.41		1
23.91810 ± 0.00092	40.5 ± 1.5	0.0918 ± 0.0023	30.8 ± 1.3		1
26.24130 ± 0.00037	42.72 ± 0.68	1.5778 ± 0.0057	44.82 ± 0.47		1
27.29750 ± 0.00096	33.7 ± 1.4	0.1337 ± 0.0037	−3.44 ± 0.15		1
35.4730 ± 0.0010	46.6 ± 2.3	0.280 ± 0.014	5.51 ± 0.27		1
41.4230 ± 0.0010	23.3 ± 1.2	1.767 ± 0.089	−5.12 ± 0.26		1
44.4810 ± 0.0010	40.8 ± 2.0	49.2 ± 2.4	−1.296 ± 0.065		1

Table 2. Comparison of ^{239}Pu integrated cross sections

	$\int_{E1}^{E2} \sigma_f dE$, in b·eV							
E Low (eV)	Our analysis	Gwin *et al.* 1984	Weston and Todd 1984[a]	Wagemans *et al.* 1980	Blons	Gwin *et al.* 1976	RPI	ENDF-V
0.01	9.74	9.70 ± 0.08						9.66
0.02	44.85	44.65 ± 0.07					44.63	44.50
0.1	460.9	461.2 ± 2.3		475.6			465.5	460.9
0.5	38.42	38.13 ± 0.51		39.29			38.93	38.21
1.0	234.4	244.9 ± 3.8		255.2		257.1	253.0	255.6
10.0	1011	1051 ± 8		1038		1035	1036	1041
20.0	318.6	315.9 ± 3.6	316.6 ± 1.6	322.5		323.5	325.9	325.0
30.0	30.2	30.95 ± 1.8	30.7 ± 0.4			34.35	30.2	34.2
40.0	256		256 ± 1		286	244	257	259
50.0	2816		2828 ± 5		2972	2852	2806	2843
100.0	1787		1798 ± 3		1891	1801	1819	1837
200.0	1712		1723 ± 4		1779	1791	1838	1765
(300.0)								
Thermal value (b)	748.4	—	741.7	741.9	—	741.7	741.6	741.7

[a]Statistical uncertainty only. Systematic uncertainty is ~2%.

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